APPENDIX C
EXAMPLES OF AIR STRIPPING BY LOW PROFILE SIEVE TRAY DEVICE

C-1. Example in SI Units. This example will illustrate a method of making preliminary design calculations to size a low profile sieve tray air stripper. Final designs depend heavily on the design of the trays. Unfortunately, this information is often not available to the designer. As a result, the final design and size of the unit must be determined from information supplied by the manufacturer. Low profile sieve tray air strippers are usually secured as complete units assembled on skids at the factory and shipped as a unit rather than being designed and constructed from job drawings and specifications. The steps in the preliminary design calculations follow (refer to Figure C-1).

- Determine the minimum and maximum volume of water to be air stripped, the minimum temperature of the water, and the maximum concentration of volatile organic chemicals (VOC) in the untreated water to be air stripped.

- Determine the desired concentration (percent removed) of the VOC in the treated water.

- Calculate the theoretical number of sieve trays needed to remove the VOC to the desired concentration.

- Estimate the tray efficiency and the number of actual trays needed.

- Estimate the size (cross-sectional area) of the perforated plate section of each tray.

- Estimate the pressure drop through the air stripper.

- Estimate the size of the air blower motor (kW).

a. Determine the volume of water to be air stripped, the minimum temperature of the water, and concentration of all the volatile organic chemicals (VOC) in the untreated water. The inlet water contains 10 mg/L of the volatile organic chemical (VOC) trichloroethylene (TCE). (Note: If the inlet water contains more than one VOC, repeat the process for each to estimate the number of trays needed for each VOC. Use the largest number of trays for the estimated design.) The flow rate of water to be treated is 0.2 m^3 per minute. The minimum temperature of the water is 20°C.

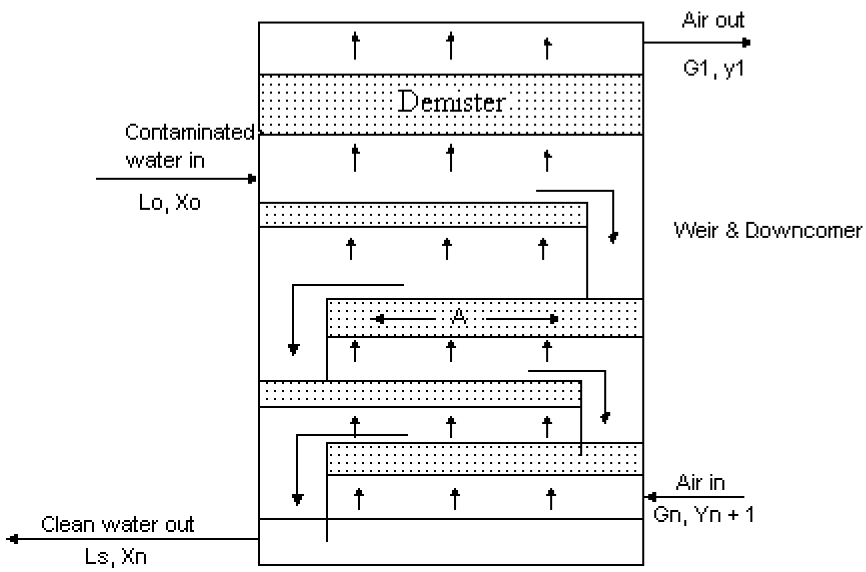

Figure C-1. Cross-sectional area of perforated plate section.

b. Determine the desired concentration of the TCE in the treated water. The desired concentration of TCE in the discharge water is 0.1 mg/L (99% removal).

c. Calculate the theoretical number of sieve trays needed to remove the VOC to the desired concentration. The theoretical number of trays required is estimated by using the following relationship (Treybal, 1980):

$$N_{\text{theoretical}} = \frac{\log\left[\dfrac{X_0 - \dfrac{Y_{n+1}}{m}}{X_n - \dfrac{Y_{n+1}}{m}}\left(1 - \dfrac{1}{S}\right) + \dfrac{1}{S}\right]}{\log S}$$

where

X_0 = concentration of contaminant (TCE) in the inlet water phase: 10 mg/L

X_n = concentration of contaminant (TCE) in the treated water phase: 0.1 mg/L

N	=	number of theoretical plates. Assumes that the liquid on each plate is completely mixed and that the vapor leaving the plates is in equilibrium with the liquid.
H	=	Henry's constant (kPa)
m	=	slope of equilibrium curve (H/Pt)
G	=	kg-moles air/min
L	=	kg-moles of water/min
Pt	=	ambient pressure (kPa)
S	=	stripping factor (mG/L)
Y_{n+1}	=	concentration of volatiles in the air entering the air stripper.

(1) For air stripping $Y_{n+1} = 0$ (the concentration of TCE in the air entering the air stripper is zero) and the equation becomes:

$$N_{\text{theoretical}} = \frac{\log\left[\frac{(X_0)}{(X_n)}\left(1-\frac{1}{S}\right)+\frac{1}{S}\right]}{\log S}$$

(2) In this example, the inlet concentration of TCE (X_0), the desired outlet concentration of TCE (Xn), the liquid temperature, and flow rate are known. The airflow rate (G) must be determined and is related to the perforated plate area of each tray. Several combinations of airflow rates and number of trays should be calculated to determine the best economic balance between having more trays and a lower airflow rate (higher capital costs vs. lower operating costs) and fewer trays and a higher air flow rate (lower capital costs vs. higher operating costs). An economic comparison is beyond the scope of this example. For this example use an air-to-water ratio of 37 m^3 of air to 1 m^3 of water (see paragraph 5-5).

(3) Substituting into the above equation yields:

$H = 5.57\times10^4$ kPa (for TCE at 20°C)

Pt = 101 kPa (101 kPa at sea level, 86 kPa at 1500 m elevation)

$$m = \frac{H}{Pt} = \left(\frac{5.57\times10^4\ \text{kPa}}{101\text{kPa}}\right) = 551\frac{\text{mole H}_2\text{O}}{\text{mole}} = \frac{551\text{kgmoleH}_2\text{O}}{\text{kgmoleair}}$$

$$G = \frac{37\text{m}^3\ \text{air}}{\text{min}} \times \frac{\text{kg}-\text{moleair}}{24.0\text{m}^3\ \text{air}@20^\circ\text{C}} = 1.54\ \frac{\text{kg}-\text{moleair}}{\text{min}}$$

$$L = \frac{1\text{m}^3\ \text{H}_2\text{O}}{\text{min}} \times \frac{1000\text{kgH}_2\text{O}}{\text{m}^3\ \text{H}_2\text{O}} \times \frac{\text{kgmoleH}_2\text{O}}{18\text{kg H}_2\text{O}} = \frac{55.6\text{ kg}-\text{moleH}^2\text{O}}{\text{min}}$$

$$S = \left(\frac{551\text{kg mole H}_2\text{O}}{\text{kgmoleair}}\right)\left(\frac{1.54\text{kgmole}\ \frac{\text{air}}{\text{min}}}{55.6\text{kgmole}\ \frac{\text{water}}{\text{min}}}\right)$$

$$= 15.3$$

$$N_{\text{theor}} = \frac{\log\left[\frac{10\ \frac{\text{mg}}{\text{L}}}{0.1\ \frac{\text{mg}}{\text{L}}} \times \left(1 - \frac{1}{15.3}\right) + \frac{1}{15.3}\right]}{\log 15.3} = 1.66$$

d. Estimate the tray efficiency and the number of actual trays needed. In actual practice a condition of complete equilibrium does not exist. The overall plate efficiency is:

$$E = \frac{N_{\text{theoretical}}}{N_{\text{actual}}}$$

Rearranging gives the number of actual trays as:

$$N_{\text{actual}} = \frac{N_{\text{theoretical}}}{E}$$

The efficiency is highly dependent on the design of the trays and the vapor flow rate. From manufacturer's data, the appropriate range appears to be E = 0.4 to 0.6 (i.e., 40 to 60% efficient). Using the above relationship and assuming 50% tray efficiency, and substituting into the above equation, gives the number of actual trays needed as:

$$N_{\text{actual}} = \frac{1.66}{0.50} = 3.32 = 4$$

e. Estimate the size (cross-sectional area) of the perforated plate section of each tray. The cross-sectional area of the perforated plate section of each tray is related to the airflow rate; 9 to 18 m^3 per minute per m^2 of tray area is common (see Paragraph 5-4). For this example, use 18 m^3 per minute per m^3 of tray area. The area is:

$$\frac{0.2\,\mathrm{m^3\,H_2O}}{\mathrm{min}} \times \frac{37\,\mathrm{m^3\,air}}{\mathrm{m^3\,H_2O}} \times \frac{\mathrm{m^2\ platearea}}{18\ \mathrm{m^3}\ \frac{\mathrm{air}}{\mathrm{min}}} = 0.41\,\mathrm{m^2}$$

Estimate that the downcomer and weir area is 20% of each plate. The total cross-sectional area of each plate is:

$$0.41\mathrm{m}^2 + 0.41 \times 0.2\mathrm{m}^2 = 0.49\ \mathrm{m}^2$$

f. Estimate the pressure drop through the air stripper. Most of the pressure drop through the air stripper is from the head of liquid on each tray times the number of trays. The depth of liquid on the trays typically varies from 8 to 12 cm of water. Assume 10 cm water for this example. The other pressure drop is from the piping from the blower to the air stripper and inlet and exit losses in the column. This will vary from system to system. An estimate for these losses is 25 cm water. From this information, the total pressure drop through the system is as follows:

$$N\ \mathrm{trays} = 3.32;\ \mathrm{round\ up\ to}\ 4$$

$$4\ \mathrm{trays} \times 10\mathrm{cm}\ \frac{\mathrm{H_2O}}{\mathrm{tray}} + 25\mathrm{cm}\ \mathrm{H_2O} = 65\mathrm{cm}\ \mathrm{H_2O}$$

g. Estimate the size of the blower motor (kW). The size of the blower motor is a function of the flow rate of air and the pressure drop. Methods of estimating the size of the blower motor can be found in reference books (McCabe et al., 1993; Avallone and Baumeister, 1987; Perry, 1984) and will not be calculated in this example.

C-2. Example in English Units. This example will illustrate a method of making preliminary design calculations to size a low profile sieve tray air stripper. Final designs depend heavily on the design of the trays. Unfortunately, this information is often not available to the designer. As a result, the final design and size of the unit must be determined from information supplied by the manufacturer. Low profile sieve tray air strippers are usually secured as complete units assembled on skids at the factory and shipped as a unit rather than being designed and constructed from job drawings and specifications. The steps in the preliminary design calculations follow (refer to Figure C-1).

- Determine the minimum and maximum volume of water to be air stripped, the minimum temperature of the water, and the maximum concentration of volatile organic chemicals (VOC) in the untreated water to be air stripped.

- Determine the desired concentration (percent removed) of the VOC in the treated water.

- Calculate the theoretical number of sieve trays needed to remove the VOC to the desired concentration.
- Estimate the tray efficiency and the number of actual trays needed.
- Estimate the size (cross-sectional area) of the perforated plate section of each tray.
- Estimate the pressure drop through the air stripper.
- Estimate the size of the blower motor (hp).

a. Determine the volume of water to be air stripped, the minimum temperature of the water and concentration of all the volatile organic chemicals (VOC) in the untreated water. The inlet water contains 10 mg/L of the volatile organic chemical (VOC) trichloroethylene (TCE). (Note: If the inlet water contains more than one VOC, repeat the process for each to estimate the number of trays needed for each VOC. Use the largest number of trays for the estimated design.) The flow rate of water to be treated is 50 gpm. The minimum temperature of the water is 60°F.

b. Determine the desired concentration of the TCE in the treated water. The desired concentration of TCE in the discharge water is 0.1 mg/L (99% removal).

c. Calculate the theoretical number of sieve trays needed to remove the VOC to the desired concentration. The theoretical number of trays required is estimated by using the following relationship (Treybal, 1980):

$$N_{\text{theoretical}} = \frac{\log\left[\dfrac{\left(X_0 - \dfrac{Y_{n+1}}{m}\right)}{\left(X_n - \dfrac{Y_{n+1}}{m}\right)}\left(1-\dfrac{1}{S}\right) + \dfrac{1}{S}\right]}{\log S}$$

where

X_0	=	concentration of contaminant (TCE) in the inlet water phase: 10 mg/L
X_n	=	concentration of contaminant (TCE) in the treated water phase: 0.1 mg/L
N	=	number of theoretical plates. Assumes that the liquid on each plate is completely mixed and that the vapor leaving the plates is in equilibrium with the liquid.
H	=	Henry's Constant (atm)
m	=	slope of equilibrium curve (H/Pt)

G	=	lb-moles air/min
L	=	lb-moles of water/min
S	=	stripping factor (mG/L)
Pt	=	ambient pressure (atm)
Y_{n+1}	=	concentration of volatiles in the air entering the air stripper.

(1) For air stripping $Y_{n+1} = 0$ (the concentration of TCE in the air entering the air stripper is zero) and the equation becomes:

$$N_{\text{theoretical}} = \frac{\log\left[\left(\frac{X_0}{X_n}\right)\left(1-\frac{1}{S}\right)+\frac{1}{S}\right]}{\log S}$$

(2) In this example, the inlet concentration of TCE (X_0), the desired outlet concentration of TCE (Xn), and the liquid temperature and flow rate are known. The airflow rate (G) must be determined and is related to the perforated plate area of each tray. Several combinations of air flow rates and number of trays should be calculated to determine the best economic balance between having more trays and a lower air flow rate (higher capital costs vs. lower operating costs) and fewer trays and a higher air flow rate (lower capital costs vs. higher operating costs). An economic comparison is beyond the scope of this example. For this example use an air-to-water ratio of 5 cfm of air to 1 gpm of water.

(3) Substituting into the above equation yields (for TCE at 20ºC):

$$H = 550\text{atm}$$

$$Pt = 1.0\text{atm}(\text{Note:}1.0\text{atm at sea level}, 0.86\text{atm at }5000\text{ft})$$

$$m = \frac{H}{Pt} = \frac{550\text{atm}}{1\text{atm}} = \frac{550\text{ lb-mole}H_2O}{\text{lb-mole air}}$$

$$G = \frac{5\text{ft}^3}{\text{min}} \times \frac{\text{lb}-\text{mole air}}{380\text{ft air}\left(@60^\circ\text{F}\right)} = 0.0132\,\frac{\text{lb}-\text{mole air}}{\text{min}}$$

$$L = \frac{1\text{gal}}{\text{min}} \times \frac{8.34\text{lb}H_2O}{\text{gal }H_2O} \times \frac{\text{lb}-\text{mole}H_2O}{18\text{lb}} = \frac{0.463\text{lb}-\text{mole }H_2O}{\text{min}}$$

$$S = \frac{550\ \text{lb-mole H}_2\text{O}}{1\text{lb-mole air}} \times \frac{0.0132\text{lb} - \text{mole/min}}{0.463\text{lb} - \text{mole/min}} = 15.7$$

$$N_{\text{theor}} = \frac{\log\left[\dfrac{10\dfrac{\text{mg}}{\text{L}}}{0.1\dfrac{\text{mg}}{\text{L}}} \times \left(1 - \dfrac{1}{15.7}\right) + \dfrac{1}{15.7}\right]}{\log 15.7} = 1.65$$

d. Estimate the tray efficiency and the number of actual trays needed. In actual practice, a condition of complete equilibrium does not exist. The overall plate efficiency is:

$$E = \frac{N_{\text{theoretical}}}{N_{\text{actual}}}$$

Rearranging gives the number of actual trays as:

$$N_{\text{actual}} = \frac{N_{\text{theoretical}}}{E}$$

The efficiency is highly dependent on the design of the trays and the vapor flow rate. From manufacturer's data, the appropriate range appears to be $E = 0.4$ to 0.6 (i.e. 40 to 60% efficient). Using the above relationship and assuming 50% tray efficiency, and substituting into the above equation, gives the number of actual trays needed as:

$$N_{\text{actual}} = \frac{1.65}{0.50} = 3.3 = 4$$

e. Estimate the size (cross-sectional area) of the perforated plate section of each tray. The cross-sectional area of the perforated plate section of each tray is related to the airflow rate; 30 to 60 cfm/ft^2 is common (see Paragraph 5-4) For this example, use 60 cfm/ft^2. Using this and the air-to-water ratio of 5 cfm of air to 1 gpm of water and the water flowrate of 50 gpm gives the cross-sectional area as

$$50\,\text{gpm} \times \frac{5\,\text{cfm}}{1\,\text{gpm}} = 250\ \text{cfm}$$

$$250\,\text{cfm} \times \frac{1\,\text{ft}^2}{60\,\text{cfm}} = 4.17\,\text{ft}^2$$

Estimate that the downcomer and weir area is 20% of each plate. The total cross-sectional area of each plate is:

$$4.17 + 4.17 \times 0.2 = 5.0\,\text{ft}^2$$

f. Estimate the pressure drop through the air stripper. Most of the pressure drop through the air stripper is from the head of liquid on each tray times the number of trays. The depth of liquid on the trays typically varies from 3 to 5 in. of water. Assume 4 in. for this example. The pressure drop from the air flowing through the holes in the sieve tray is usually insignificant to the other pressure drops in the system and will be ignored for this example. The other pressure drop is from the piping from the blower to the air stripper and inlet and exit losses in the column. This will vary from system to system. An estimate for these losses is 10 in. From this information the total pressure drop through the system is as follows:

$$N\ \text{trays} = 3.3;\ \text{round up to } 4$$

$$4\ \text{trays} \times 4\,\text{in.wg}\ \frac{H_2O}{\text{tray}} + 10\,\text{in.wg}\,H_2O = 26\,\text{in.wg}\,H_2O$$

g. Estimate the size of the blower motor (hp). The size of the blower motor is a function of the flow rate of air and the pressure drop. Methods of estimating the size of the blower motor (hp) can be found in reference books (McCabe et al., 1993; Avallone and Baumeister, 1987; Perry, 1984) and will not be calculated in this example.